Different management strategies exert distinct influences on microclimate of soil-atmosphere system in tea fields

Siang-Heng Wang[1] and Jehn-Yih Juang[1]

[1]National Taiwan University

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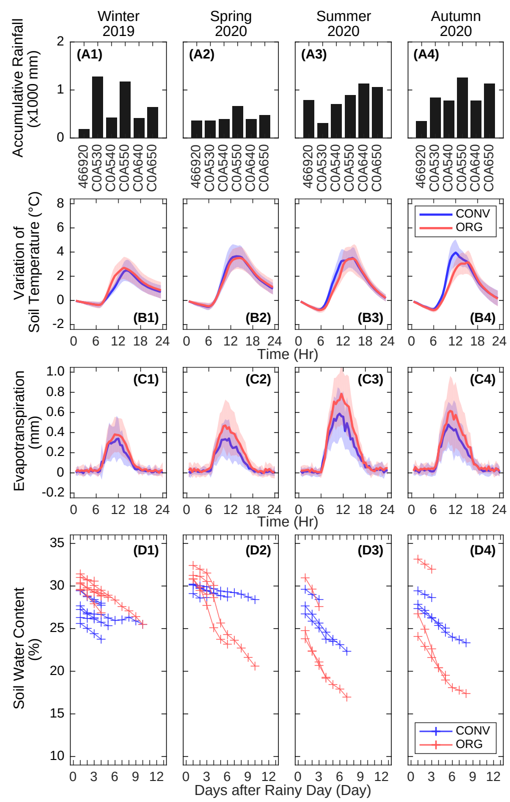
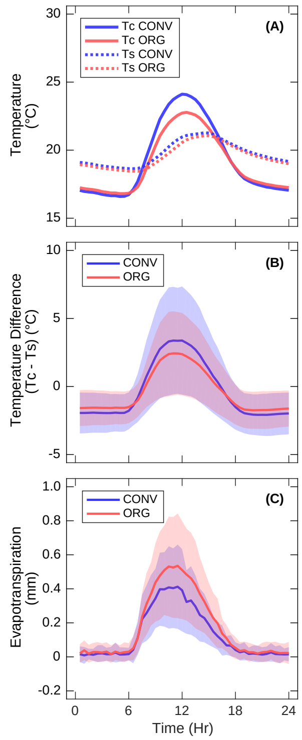
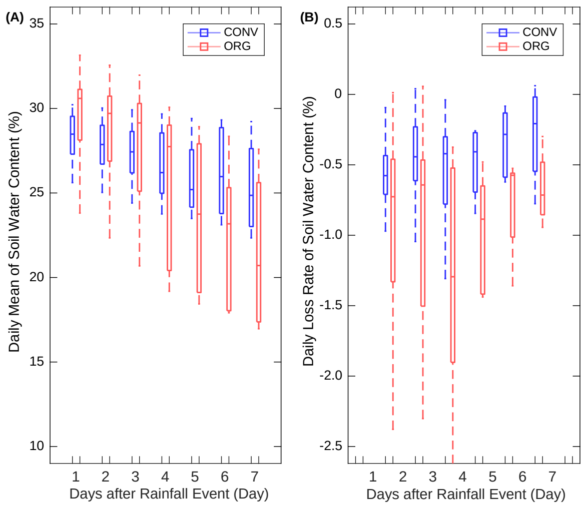
Abstract

Agricultural management strategies are crucial in regulating the soil-atmosphere interaction. The crop landscape is influenced by farmers through different field practices, and further impacts the variations of soil temperature, soil moisture, and field microclimate. To examine how different management strategies affect the soil properties and the aforementioned interaction, two observation systems were installed in an organic-certified (ORG) tea field and a conventional (CONV) tea field in northern Taiwan. The results show that the variation of canopy temperature was more significant in CONV while the difference in soil diurnal temperature range was minor. However, the daily loss rate of soil water content in ORG was two times faster than that in CONV (0.93% d-1 vs. 0.46% d-1). These findings suggest that the appropriate management strategies could assist farmers in adapting to environmental fluctuations and provide quantitative references for assessing soil characteristics under different agricultural applications and climatic conditions.


Winter 2019
Spring 2020
Summer 2020
Autumn 2020
Accumulative Rainfall (x1000 mm)
(A1)
(A2)
(A3)
(A4)
466920
C0A530
C0A540
C0A550
C0A640
C0A650
Variation of Soil Temperature (°C)
(B1)
(B2)
(B3)
(B4)
CONV
ORG
Time (Hr)
Evapotranspiration (mm)
(C1)
(C2)
(C3)
(C4)
Time (Hr)
Soil Water Content (%)
(D1)
(D2)
(D3)
(D4)
CONV
ORG
Days after Rainy Day (Day)


(A)
Tc CONV
Tc ORG
Ts CONV
Ts ORG
Temperature (°C)
(B)
CONV
ORG
Temperature Difference (Tc - Ts) (°C)
(C)
CONV
ORG
Evapotranspiration (mm)
Time (Hr)



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Title

Different management strategies exert distinct influences on microclimate of soil-atmosphere system in tea fields

Authors

Siang-Heng Wang [1, 2] and Jehn-Yih Juang [1, 2, *]

Affiliation

1. International Degree Program in Climate Change and Sustainable Development, National Taiwan University, Taipei, Taiwan
2. Department of Geography, National Taiwan University, Taipei, Taiwan

Corresponding: Jehn-Yih Juang

Abstract

Agricultural management strategies are crucial in regulating the soil-atmosphere interaction. The crop landscape is influenced by farmers through different field practices, and further impacts the variations of soil temperature, soil moisture, and field microclimate. To examine how different management strategies affect the soil properties and the aforementioned interaction, two observation systems were installed in an organic-certified (ORG) tea field and a conventional (CONV) tea field in northern Taiwan. The results show that the variation of canopy temperature was more significant in CONV while the difference in soil diurnal temperature range was minor. However, the daily loss rate of soil water content in ORG was two times faster than that in CONV (0.93% d^{-1} vs. 0.46% d^{-1}). These findings suggest that the appropriate management strategies could assist farmers in adapting to environmental fluctuations and provide quantitative references for assessing soil characteristics under different agricultural applications and climatic conditions.

Keywords: organic; conventional; soil temperature; soil moisture; evapotranspiration (ET); eddy covariance (EC)

Plain Language Summary

In agricultural fields, the farmers frequently utilize different field applications, such as pruning, weeding, or soil loosening, to manage their crops. The application of these different agricultural management strategies usually changes the appearance of the crop canopy, and further influences the soil properties and the water conservation in these crop fields. To quantify how field management influences these properties, two sets of micro-meteorological measurement systems were conducted in an organic-certified and a conventional tea field in northern Taiwan. According to the ensemble average of the measurements, the difference in soil temperature was minor but the difference in canopy temperature was significantly larger in conventional field. However, the daily loss rate of soil water content in the organic-certified field was faster than that in the conventional field. The variation in soil water content was stronger than that in the conventional field. The findings from this study could sufficiently provide quantitative knowledge for field management in the agricultural fields.

Key Points

1. Field management is crucial in soil-atmosphere interaction through the changes in canopy structure and soil properties.
2. The difference in soil DTR is minor, but the loss of soil water content is faster in the organic-certified field than conventional field.
3. High evapotranspiration in the organic-certified tea field corresponds to a high rate of decrease in soil water content.

1. Introduction

The long-term interaction between canopy volume and the dynamics of soil parameters (soil temperature, T_s, and soil moisture) has been investigated through modeling and field surveys (Childs and Flint, 1987; Famuwagun, 2016; Flerchinger and Pierson, 1991; Ritter *et al.*, 2005). Canopy coverage obstructs incident solar radiation, causes changes in surface energy balance and evapotranspiration (ET) (Kustas *et al.*, 2018) and alters T_s through canopy shading (Özkan and Gökbulak, 2017). The partitions of the surface net radiation, sensible heat flux, and latent heat flux are also influenced by variations in canopy coverage (Baldocchi, 1994). Furthermore, canopy coverage influences soil evaporation because of changes in the canopy structure. In addition, evaporation, combined with infiltration and percolation of rainwater and dew in the soil layer, notably contributes to soil moisture dynamics (Wang and Dickinson, 2012).

Vegetation canopy regulates the microclimatic factors of above-ground and underground components through energy and water cycles; thus, canopy coverage plays a supportive role in agriculture (Davis *et al.*, 2019; Gao *et al.*, 2019; Kustas *et al.*, 2018; Lin, 2007; 2010; Özkan and Gökbulak, 2017). Hirsch *et al.* (2018) discovered that agricultural management can influence the spatial pattern of soil evaporation, whose trend is opposite to that of canopy transpiration on a global scale. Canopy coverage directly influences the ratio of transpiration to evaporation

(Lin, 2010; Villalobos *et al.*, 2009) and the dynamics of soil moisture (Lin, 2007). Furthermore, soil moisture is also controlled by ET and ambient temperature through near-surface climate feedback (Berg *et al.*, 2014). High near-surface air temperature might cause an increase in soil moisture due to the less canopy greenness and lower transpiration ability (Zavaleta *et al.*, 2003). A modeling-based study discovered that the effects of the interactions between soil moisture and the atmosphere account for 50% of the effects on T_s, especially in the case of representative concentration pathway 4.5 (RCP4.5) (Diro and Sushama, 2017).

Unlike in forests, the interactions between soil moisture and the atmosphere on agricultural land are readily influenced by the dominant exchange of radiation and moisture through the canopy layer because the vegetation coverage is lower on such land than that in forests. Canopy shading is a key factor influencing the microclimate of agricultural fields (Bhagat *et al.*, 2016). Famuwagun (2016) demonstrated that the canopy shading in a cocoa field reduced T_s 4 months after plantation by approximately 7.7 °C, which indicated that the canopy shading regulated solar heating over different growth periods. With a decrease in the incident radiation, less energy is available for the evaporation of water and for increasing the ambient temperature. In previous studies, a coffee field with higher canopy shading exhibited a 41% and approximately 2 °C lower soil evaporation rate and ambient temperature, respectively, than did a field with lower canopy shading (Lin, 2007; 2010).

Research on soil water content mostly focused on the time series of soil moisture (Almagro *et al.*, 2009; Gao *et al.*, 2019; Liang *et al.*, 2014; Lin, 2010; Zheng *et al.*, 2019) but rarely explored its variations in change rate. These studies have reported on the soil moisture dynamics in various conditions. Because of the limitations of topographical or environmental conditions, crop growth in some fields relies only on rainfall and not on irrigation. Therefore, knowledge on the variations in soil water content after every rainfall event is crucial for farmers and scientists during short-term meteorological fluctuations and in different climate scenarios. However, few studies have investigated the variations in soil moisture in terms of change rate or compared various field management strategies. The present study investigated the patterns of T_s, soil moisture, and ET in two neighboring tea fields with different field management strategies to explore the influence of field management strategies on these microclimate parameters.

2. Study site and methods

2.1. Study site

On-site measurements were conducted in two nearby tea fields (121.7279°E, 24.9645°N, elevation ~600 m above sea level) on a hilly terrain in Pinglin Township, New Taipei City, northern Taiwan, which is a region in which tea cultivation is the leading occupation (Wang and Juang, 2022). The tea fields in the Pinglin region have desirable canopy heights, crown sizes, leaf area density, and corridor width that satisfy the expectations of the farmers. The farmers in this region adopt management strategies based on their long-term local experience, and modification of the canopy structure is the primary approach for applying these strategies. For example, tea farmers frequently shape the tree crown by pruning the branches and leaves to modify the sunshine, ventilation, and water statuses of their field. Therefore, the analysis of the microclimate of the study area by comparing the energy components and soil parameters in nearby fields with similar meteorological and geographical conditions can enhance the fundamental understanding on how field management affects the microclimate.

The two neighboring tea fields (separated by approximately 100 m) investigated in this study, in which different management strategies are used (Table 1), exhibit similar environmental and geographical parameters, including topographic slope, orientation, fetch area, elevation, and sky openness (Wang and Juang, 2022). One of the fields is an organic-certified field (ORG) in which labor-intensive applications, such as manual weeding and harvesting, are relatively common. By contrast, the other field is a conventional field (CONV) in which farmers typically use herbicide to eliminate weeding and adopt machines for harvesting.

Because the strategies adopted by the farmers are different for the two fields, their canopy structures are controlled and shaped through field operations. The tea tree crown in ORG was taller and more extensive than that in CONV. Furthermore, the ground surface in ORG was notably covered by weed, whereas the ground surface of CONV was not covered by weed because of the frequent usage of herbicide but was covered with dry leave debris. Research (Wang and Juang, 2022) conducted at this study site indicated that ORG, which had a wider and taller canopy than did CONV, exhibited a higher latent heat flux (25%) and lower sensible heat flux (10%) than did CONV. Furthermore, after the tea buds were harvested, the sensible heat flux increased by 51.5% in CONV but only by 9.6% in ORG.

Although Pinglin is a wet area (the long-term annual rainfall is approximately 4,000 mm), the seasonality in rainfall is notable (the rainfall is approximately 200 mm during spring but exceeds 1,000 mm during autumn). The rainfall patterns over different seasons were compared according to the accumulative rainfall acquired from five automatic weather stations and one meteorological station of the Central Weather Bureau in Taiwan near the study fields.

2.2. Physical properties of the soil in the two fields

Because the two tea fields managed using different strategies were adjacent to each other, the physical properties of the soil layers in these fields were affected by the different farmers' applications in the fields on a long-term basis. For example, the biological activities and root systems in ORG were more likely to cause the soil to loosen than were those of CONV. Measuring soil bulk density is a common method for characterizing soil structural properties (Dexter, 2004; Rabot *et al.*, 2018).

Soil bulk density was measured from soil samples excavated from the northern, middle, and southern sides of the corridor near the soil moisture sensor. The volume and depth of the sampling core were 98 cm^3 and 5 cm, respectively. Before sampling was performed, the bulk debris cover on the soil surface was carefully removed, but the humus in the soil was kept intact. The core was vertically inserted into the soil, after which the soil samples were excavated. The sample tube was then covered using a plastic lid to avoid evaporation. Each soil sample was dried at 105°C for 24 h. The dried soil samples were then weighed, and the bulk density was calculated as the dried soil weight divided by the core volume (Klute, 1986).

2.3. Soil temperature, canopy temperature, and soil moisture measurement

In the study region, tea plants are typically planted in rows in parallel corridors, and the landscape has an inhomogeneous appearance. This inhomogeneity was expected to influence the representativeness of the measurements and should be considered when assessing the soil layer (Michot *et al.*, 2003). To consider the spatial representativeness of the tea fields, pairs of soil temperature and water content sensors (Drill and Drop, Sentek Inc., Stepney, SA, Australia) were installed on the northern and southern corridors near an eddy-covariance (EC) flux system in each field. The detectors were placed 5 cm below the ground surface to perform measurements from June 2019 to October 2020. The canopy temperature (T_c) were measured at the tree crown by a T-type thermocouple with radiation shield. The data was collected using a data logger (CR1000X, Campbell Scientific, Inc., Logan, UT, USA) at a sampling frequency of 1 min^{-1}.

The measurement data collected from the winter of 2019 to the autumn of 2020 were divided among four seasons because the ground surface temperature was sensitive to solar radiation. To quantify how field applications affect the patterns of field temperature, the half-hourly time series of temperature difference between T_c and T_s (T_c-T_s) were obtained for further analysis.

2.4. ET measurement

ET was estimated using an EC flux system composed of a 10-Hz sonic anemometer (CSAT-3, Campbell Scientific, Inc., Logan, UT, USA), and an open-path CO_2/H_2O gas analyzer (LI-7500, Li-Cor Inc., Lincoln, NE, USA) in each field (Wang and Juang, 2022). The EC equipment was set at heights of 1.5 m (canopy height of 1.0 m) and 1.0 m (canopy height of 0.5 m) in ORG and CONV, respectively. ET data were collected using the CR1000X data logger, and the 30-min mean ET values were calculated using the EddyPro v6.2.2 software (Li-Cor Inc., Lincoln, NE, USA). In addition, the fetch area of the flux measurement was estimated using a R package (FREddyPro v1.0). Although both fields are small (Table 1), over 90% of the flux originated from the fields because the measurement heights were low.

3. Results and discussion

3.1. Soil bulk density

According to the analysis of physical properties, the soil bulk density was 1.19 ± 0.02 g cm^{-3} in CONV and 1.10 ± 0.10 g cm^{-3} in ORG. The lower bulk density in ORG was likely on account of the higher abundance of organisms and weed roots in the soil layer in ORG because no pesticide or herbicide was used in this field. In ORG, the organisms in the soil caused the soil structure to loosen, increased the porosity for air and water, and decreased the soil aggregate stability for root development. The higher variation in soil bulk density in ORG (0.10 g cm^{-3} in

ORG and 0.02 g cm^{-3} in CONV) was consistent with these results (Rabot *et al.*, 2018). The lower aggregate stability in ORG than in CONV promoted infiltration more effectively in ORG, thereby resulting in less surface runoff in ORG (Rabot *et al.*, 2018).

3.2. Soil temperature, canopy temperature and temperature difference

T_s in the fields was influenced by canopy coverage and seasonal variation (dependent on incident solar radiation). To quantify the diurnal temperature range (DTR) over different seasons, the ensemble average of the 30-min data in CONV and ORG was converted into the DTR (the difference between each 30-min data point and the first data point) over different seasons (**B1** to **B4** in Figure 1, from the winter of 2019 to the autumn of 2020). In ORG, the DTR over the seasons was highly similar; however, the DTR in CONV was higher during autumn and winter than during other seasons. The results indicated that the DTR in CONV was higher than that in ORG during autumn (4.69 °C in CONV vs. 3.95 °C in ORG) (Figure 1 **B4**), and the DTR in CONV was lower than that in ORG during winter (2.85 °C in CONV vs. 3.07 °C in ORG) (Figure 1 **B1**). Although the DTR in autumn and winter were noticeable, the ensemble average over all seasons indicated that the DTR in CONV was similar to that in ORG (2.50 °C in CONV vs. 2.46 °C in ORG). The T_s difference in ensemble average was not significant (the maximum difference is 0.46 °C at 11:00, Figure 2 **A**).

Compared to the difference of DTR in T_s, the difference of dynamics in T_c was more notable. T_c in CONV was 0.86 °C (46.5%) higher than ORG around noon (9:00-15:00), and 0.36°C (22.3%) lower than ORG during nighttime (21:00-3:00).

As indicated by the canopy structure, the canopy coverage in ORG was higher than that in CONV (leaf area index, was 4.11 in ORG and 1.04 in CONV on May 14, 2020, as reported by Wang and Juang (2022)). An obvious heating effect in CONV occurred around the canopy (0.86 °C) due to its shorter height.

A previous study has indicated that a higher canopy shading in a coffee field can result in a lower field temperature and more beneficial to microclimate (Lin, 2007). The shading effect of a higher canopy coverage attenuates the radiation incident on the ground surface and might increase the shade tolerance of some organisms in the understory layer (Valladares *et al.*, 2016). De Frenne *et al.* (2013) reported that in addition to moderating the microclimate, a dense forest canopy might result in thermophilization lag under the forest canopy. Canopy shading has notable influence on ecophysiological characteristics, and more active abiotic and biotic ecosystem dynamics in higher shading area are observed within the canopy volume (Valladares *et al.*, 2016). Therefore, the canopy coverage in this study showed an obvious influence on the dynamics of T_c.

3.3. Soil moisture

From the data shown in Figure 1, there was no correlation pattern between the seasonal accumulative rainfall (**A1** to **A4** in Figure 1) and the consecutive daily soil water content between every rainfall events (**D1** to **D4** in Figure 1). Because Pinglin is a wet region that receives 4,000 mm of rainfall annually and a considerable amount of dew water in the morning, soil water content did not exhibit seasonal variation. The results indicated that the median daily mean soil water content after rainfall was 28.5% in CONV and 30.6% in ORG. Furthermore, after 7 days, the median changed to 24.9% in CONV and 20.7% in ORG (Figure 3 **A**). Overall, the average daily loss rate was 0.46% d^{-1} in CONV and 0.93% d^{-1} in ORG.

A study indicated that the soil water content in organic field was higher than that in conventional field because of the higher capacity of organic field to retain soil water (Lotter *et al.*, 2003). In the present study, similar results were obtained for soil water content after the rainfall event (CONV vs. ORG: 28.5% vs. 30.6%). However, the rate of soil water loss in ORG was higher than that in CONV 7 days after the rainfall event, thereby which resulted in the soil water content being lower in ORG (CONV vs. ORG: 24.9% vs. 20.7%). Lin (2010) found that lower shading in a coffee field resulted in higher soil water loss in the wet and dry seasons. However, in this study, the soil water content between rainfall events was initially 1.2% higher in ORG but then became lower with time (4.2% lower compared with CONV). This pattern indicates that the loss rate of water content was higher in ORG than in CONV.

During the first 4–5 days after a rainfall event, the daily soil water content decreased more notably in ORG than in CONV (**D1** to **D4** in Figure 1). The daily loss rate was higher on the first 4 days than on the later days (Figure 3 **B**). After the rainfall events, the median of the daily loss rate of soil water content was 0.58% d^{-1} in CONV and 0.77% d^{-1} in ORG. On the 3rd to 4th day, the daily loss rate in CONV and ORG were 0.42% d^{-1} and 1.29% d^{-1}, respectively. On the 6th to 7th day, the rate in CONV was 0.21% d^{-1}, and the rate in ORG was 0.71% d^{-1}. The daily loss rate from the 1st and 2nd days to the 4th and 5th days in the two fields were significantly different ($p < 0.05$) (Figure 3 **B**). Overall, the soil moisture dynamics in ORG were stronger than those in CONV. In ORG, the daily loss rate of soil water content increased from the beginning to the following rainfall event, but a retard situation occurred on the 4th day. The relatively fast loss of soil water content in ORG was consistent with the low soil bulk density in ORG, which resulted in a higher infiltration rate in ORG than in CONV. Therefore, the soil moisture dynamics in ORG were stronger than those in CONV.

The distribution of weed roots in ORG increased the soil porosity in ORG and caused an increase in the water holding capacity of the soil during rainfall events.

However, the increased porosity of the soil layer facilitated the evaporation of soil water after rainfall (Or *et al.*, 2013). In addition, transpiration in the weeds in ORG resulted in the loss of soil water. Moreover, the ground surface of CONV was covered with leaf debris (formed during tea plant trimming) that caused a decrease in evaporation by blocking direct solar heating. Therefore, the soil water content in ORG increased after rainfall but later decreased at a high rate, and the rainwater holding ability of the soil in CONV was higher than that of the soil in ORG.

3.4. Evapotranspiration

The difference in the daily loss rate of soil water content in terms of the ET pattern between the two fields was considerably large. The ET rate was 6.27 mm d^{-1} in CONV and 8.38 mm d^{-1} in ORG, which indicated that the ET in ORG was 33.8% higher than that in CONV. The most significant difference occurred around noon (from 10:00 to 14:00 LT). The ensemble average and maximum values of the ET in ORG over 30 min were 0.480 and 0.535 mm, respectively, and the corresponding values in CONV were 0.351 and 0.412 mm, respectively. These results were obtained around mid-day and indicated that the ET in ORG was approximately 36.8% higher than that in CONV (Figure 2). The ET patterns in the two fields were significantly different ($p < 0.001$), especially during the day (7:30–17:00). Thus, according to the ET pattern and soil water content, the loss of soil water from the ground surface in ORG was higher than that in CONV, which contributed to the ET in ORG.

The higher ET in ORG than in CONV was attributable to the taller and wider canopy structure of the tea plants and the weeds covering the ground surface in ORG. Compared to that in ORG, the tea tree canopy in CONV was shorter, thereby limiting the loss of water. The present study did not distinguish between evaporation and transpiration in the tea fields. However, according to field observations in previous studies, the long-term evaporation of soil water in CONV is limited by the leaf debris covering the ground surface (Facelli and Pickett, 1991). Transpiration had a notable influence on the ET in ORG because of the higher canopy volume in ORG than in CONV, as indicated by the leaf area index (LAI). By contrast, soil evaporation had a considerably low contribution to the ET in the Pinglin region because the annual rainfall in the region was approximately 4000 mm and the landscape was primarily covered with vegetation that contributed to water conservation.

W. Todd *et al.* (1991) suggested that wider canopy coverage on the ground surface reduced the evaporation in a corn field. Another study reported that a larger shading area in a coffee field decreased the rate of loss of the soil water content (Lin, 2010). The present study indicated that a tea field with a larger canopy coverage exhibits higher ET and superior soil moisture dynamics between rainfall events. Therefore, a larger canopy coverage contributes to enhancing ET, and the canopy volume is higher because of higher LAI (Wang *et al.*, 2014).

4. Conclusions

In the tea cultivation industry, the various management strategies adopted by tea farmers according to their expectations typically involve altering canopy structures and the microclimate of the tea field. In this study, we performed a series of measurements and analyses to examine the outcomes of different management strategies in terms of T_c, T_s, soil moisture, and ET in two neighboring tea fields in northern Taiwan. The results indicated that field applications (organic-certified and conventional methods) corresponded to differences in surface heating and soil moisture through the modification of canopy coverage.

The shorter and narrower canopy coverage in CONV than in ORG resulted in a lower rate of decrease in soil moisture after each rainfall event in CONV (–0.46% d^{-1}) than in ORG (–0.93% d^{-1}). This result was consistent with the ET pattern and indicated that the rate of ET in ORG was 2.11 mm d^{-1} (33.8%) higher than that in CONV (6.27 mm d^{-1} in CONV and 8.38 mm d^{-1} in ORG) because the canopy and weed in ORG tended to release more soil water through the root system. Furthermore, the higher ET leads to lower canopy temperature in ORG than in CONV (0.86 °C or 46.5%). In addition, the rate of decrease in soil moisture in the two fields changed drastically 3-4 days after rainfall. The loss rate was faster in the first 3-4 days than the later days, and this pattern was more significant in ORG. The lower soil bulk density in ORG can be attributed to the higher rate of decrease in soil moisture. The inverse relationship between bulk density and variations in soil water content in this study is consistent with the concept of least limiting water range (LLWR) introduced by da Silva *et al.* (1994).

The strategies used for soil water management in tea fields can serve as references for water resource management in agricultural land at the regional scale. These strategies can also help farmers determine the extent of trimming and weeding required to offset the influence of rain and drought events (Bhagat *et al.*, 2016). Lotter *et al.* (2003) reported that the water holding capacity of soil in organic crop fields is higher than in other fields. The high water holding capacity of soil is crucial for controlling the interactions between soil moisture and the atmosphere (Diro and Sushama, 2017). It dominates the energy budget (Flerchinger *et al.*, 2003) and can effectively retard floods caused by frequent extreme climate fluctuations. Furthermore, T_s and soil moisture are essential parameters that influence the crop yield (Liu *et al.*, 2013), hydrological cycle (Robinson *et al.*, 2008), biological process, and various physical responses (Legates *et al.*, 2011).

Although the influence of diurnal soil temperature difference on surface temperature is unclear, the results suggest the high correlation between coverage and surface temperature. Canopy coverage or shading in the field can moderate the surface temperature in the long term and mitigate the tradeoffs. Godinho *et al.* (2016) reported that the higher canopy coverage could lower surface temperature. In addition, the existence of cover crops could reduce soil erosion under extreme rainfall (Kaye and Quemada, 2017). Besides the geophysical effects, Schmitzberger *et al.* (2005) reported that ecofriendly agriculture has relatively low economical turnover but provides high biodiversity value. Although ecofriendly agriculture produces relatively low yields (Maeder *et al.*, 2002), the demand for fertilizers and pesticides is considerably lower than that in conventional agriculture (Schmitzberger *et al.*, 2005; Zhang *et al.*, 2018). Furthermore, organic farms have high biodiversity (Maeder *et al.*, 2002) and ecofriendly planting might increase the resilience of crop fields against rigorous climate. The results and data of this field study can serve as background information for numerical models for assessing soil characteristics as the outcomes of different management strategies and different climatic conditions.

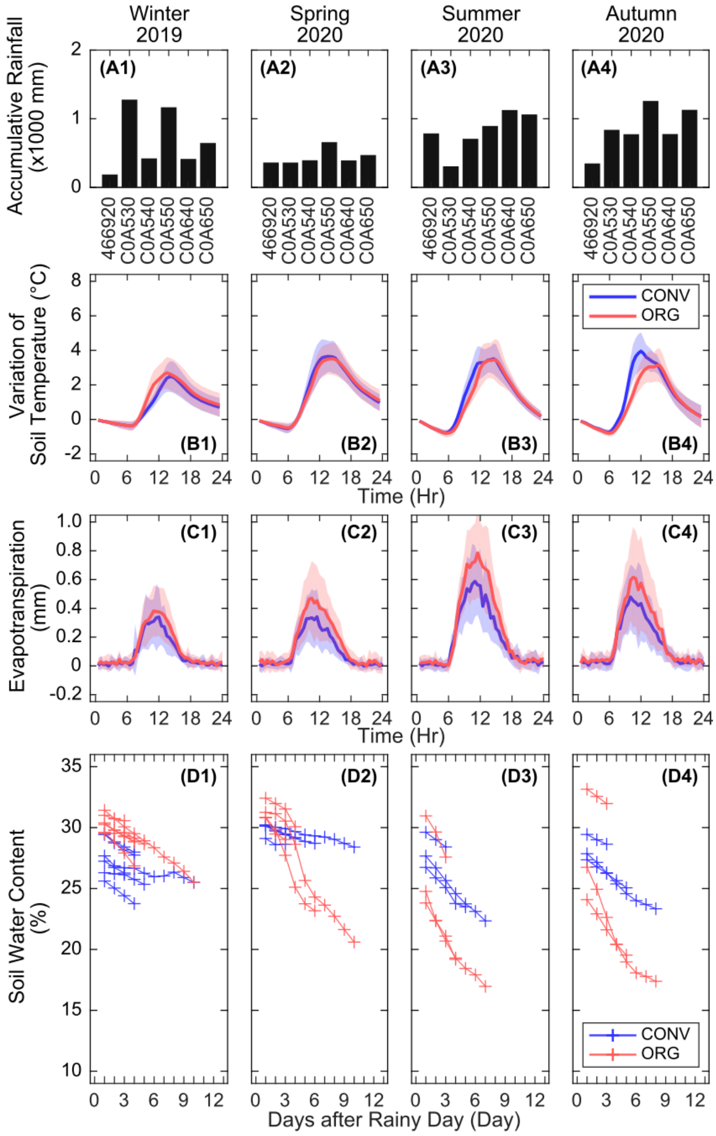

Figure 1 Seasonal cumulative rainfall **(A1 to A4)**, soil temperature **(B1 to B4)**, ET **(C1 to C4)**, and soil water content **(D1 to D4)** from the summer of 2019 to the autumn of 2020. Rainfall data were captured at six weather stations (466920: Taipei, C0A530: Pinglin, C0A540: Sihdu, C0A550: Taiping, C0A640: Shihding, C0A650: Huoshaoliao) of the Central Weather Bureau.

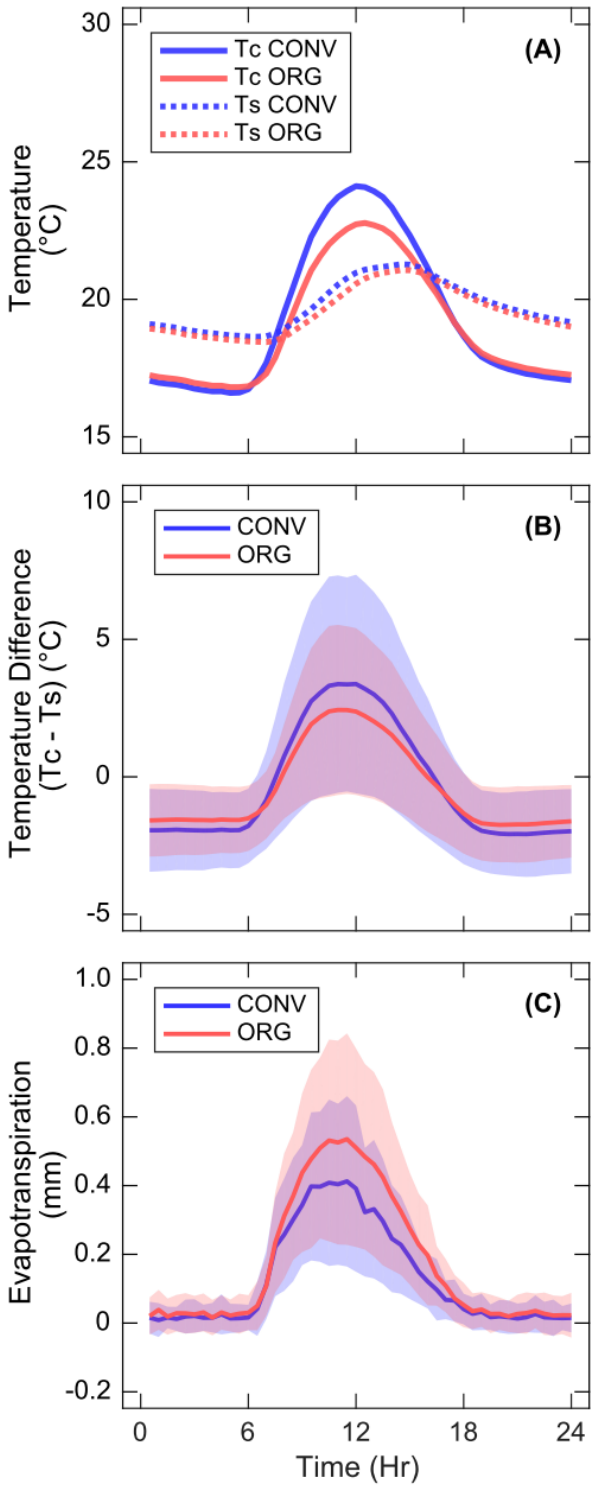

Figure 2 **(A)** Ensemble average of canopy temperature (T_c) and soil temperature (T_s), **(B)** difference between T_c and T_s, and **(C)** ensemble average values of ET during the measurement period. The solid lines and dotted lines are the ensemble averages, and the shadow area represents one standard deviation.

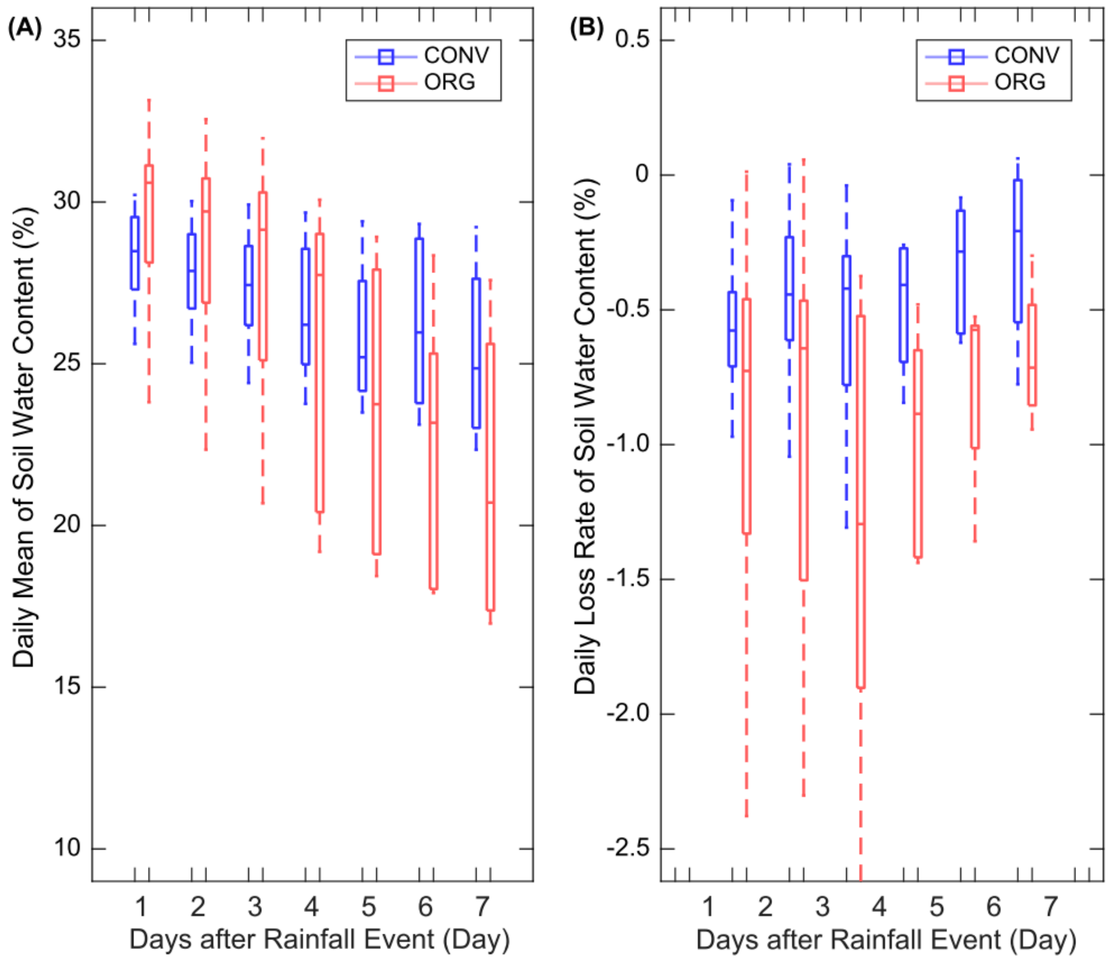

Figure 3 Daily mean (A) and daily loss rate (B) of soil water content between rainfall events. The legends in the box plot from the top to the end are the maximum (upper boundary of the dashed line), third quantile (upper boundary of the box), median (middle of the box), first quantile (lower boundary of the box), and minimum (lower boundary of the dashed line) values. The conditions of capturing rainfall data for daily loss rate were as follows: daily rainfall of less than 0.8 mm; the daily rainfall on the previous day did not exceed 1.2 mm; and the data for only 2 successive days were excluded.

Table 1 Geographical properties, management strategies, and canopy properties of the two investigated tea fields. The statistical result of FAPAR in 2018 did not pass the comparison test, and all other comparisons in 2018 and 2020 passed the Wilcoxon rank sum test.

Properties		**CONV**	**ORG**
Geographical Properties	Elevation (m)	575	580
	Slope (%)	33.0	31.7
	Heading (°)	143.1	170.3
	Area (m^2)	1234	1051
Management	Planted species	TTES #13 [1]	TTES #12
	Harvest	Machine	Manual
	Weeding	Herbicide	Manual
	Soil surface	Slight amount of moss and dry leaves	Weed
	Canopy structure	Flat	Rough
	Interrow spacing (m) [2]	1.00	1.25
Canopy on 11 Nov 2018	LAI_{Field}	2.73 ± 0.60	4.62 ± 0.79
	LAI_{Crown}	3.88 ± 0.70	5.62 ± 1.28
	FAPAR	0.88 ± 0.05	0.90 ± 0.06
	Canopy height (cm)	49.4 ± 3.34	97.7 ± 9.05
Canopy on 14 May 2020	LAI_{Field}	1.04 ± 0.29	4.11 ± 0.91
	LAI_{Crown}	1.52 ± 0.21	5.32 ± 1.03
	FAPAR	0.48 ± 0.05	0.89 ± 0.04
	Canopy height (cm)	40.5 ± 2.55	80.5 ± 4.50

[1] TTES: Taiwan Tea Experiment Station.

[2] Horizontal distance, not including tilt.

Acknowledgments

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Open Research

Data Availability Statement

The measurement data is available at https://doi.org/10.1088/1748-9326/ac4361 (Wang and Juang, 2022), and the climate data is available at Central Weather Bureau, Taiwan (https://www.cwb.gov.tw/V8/E/D/Data_Application.html)

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Figure 1.

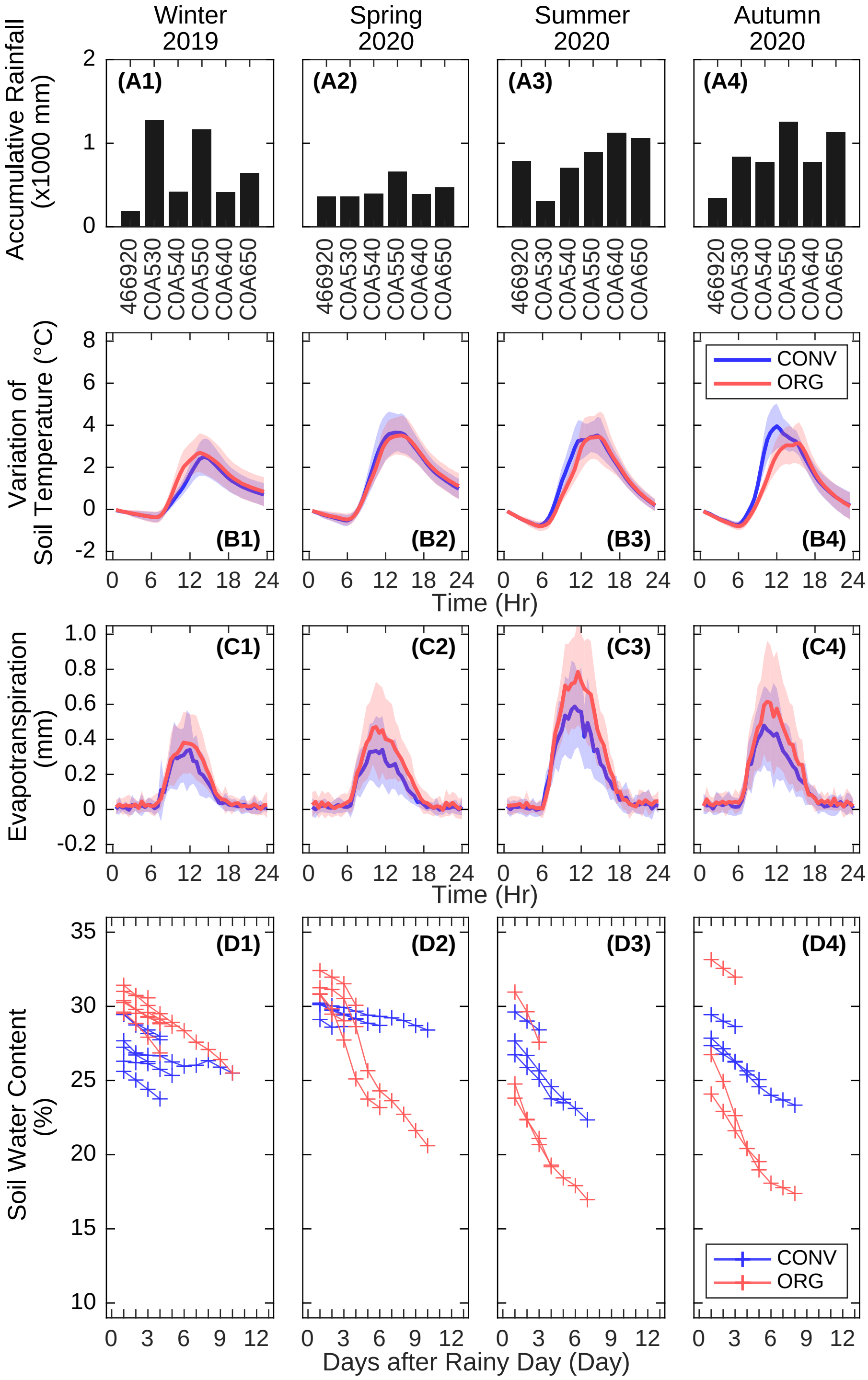
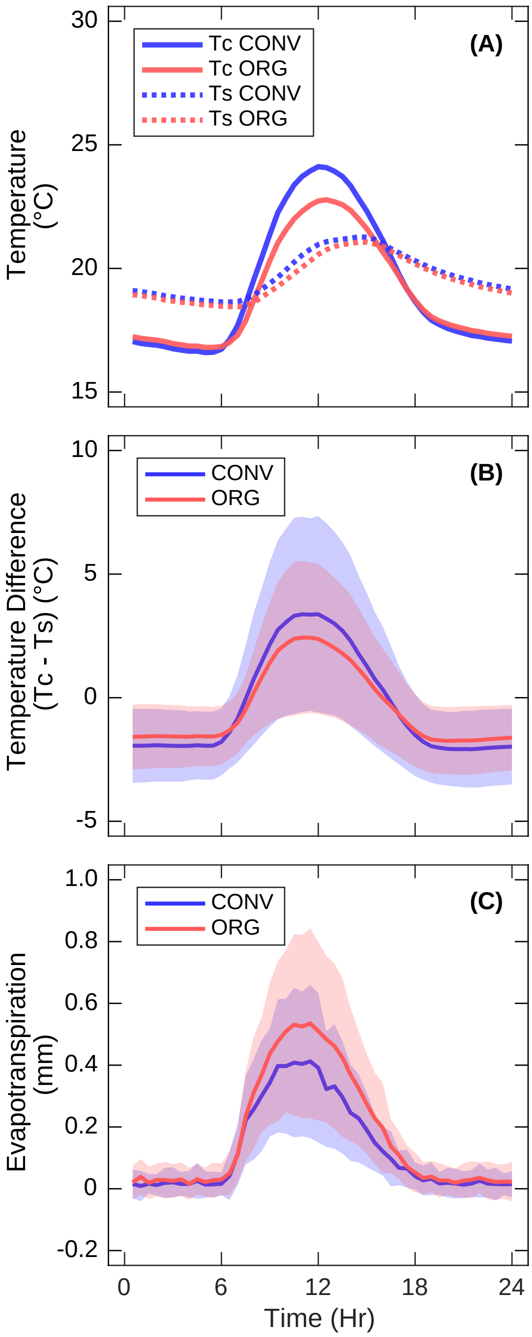
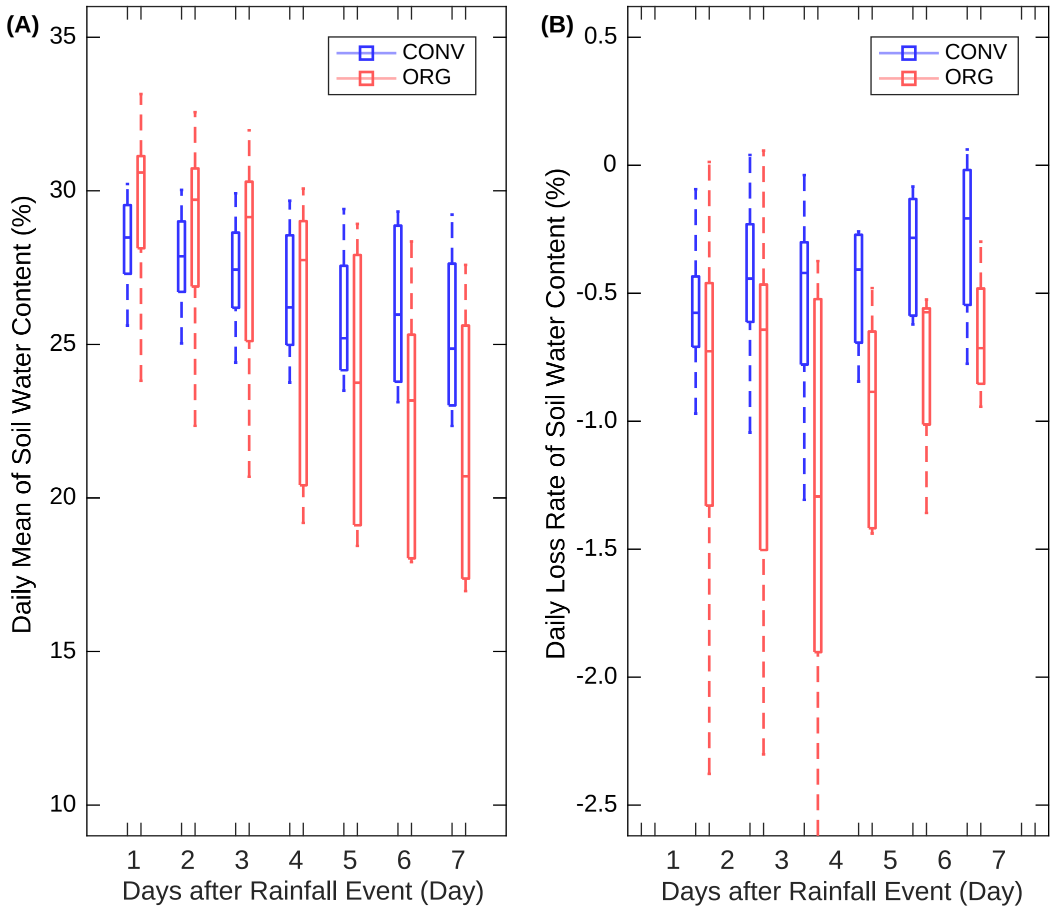

Winter 2019
Spring 2020
Summer 2020
Autumn 2020
Accumulative Rainfall (x1000 mm)
(A1)
(A2)
(A3)
(A4)
466920
C0A530
C0A540
C0A550
C0A640
C0A650
Variation of Soil Temperature (°C)
(B1)
(B2)
(B3)
(B4)
CONV
ORG
Time (Hr)
Evapotranspiration (mm)
(C1)
(C2)
(C3)
(C4)
Time (Hr)
Soil Water Content (%)
(D1)
(D2)
(D3)
(D4)
CONV
ORG
Days after Rainy Day (Day)

Figure 2.



(A)
Tc CONV
Tc ORG
Ts CONV
Ts ORG
Temperature (°C)
30
25
20
15
(B)
CONV
ORG
Temperature Difference (Tc - Ts) (°C)
10
5
0
-5
(C)
CONV
ORG
Evapotranspiration (mm)
1.0
0.8
0.6
0.4
0.2
0
-0.2
0
6
12
18
24
Time (Hr)

Figure 3.



(A)
35
30
25
20
15
10
CONV
ORG
Daily Mean of Soil Water Content (%)
1
2
3
4
5
6
7
Days after Rainfall Event (Day)
(B)
0.5
0
-0.5
-1.0
-1.5
-2.0
-2.5
CONV
ORG
Daily Loss Rate of Soil Water Content (%)
1
2
3
4
5
6
7
Days after Rainfall Event (Day)

Table 1 Geographical properties, management strategies, and canopy properties of the two investigated tea fields. The statistical result of FAPAR in 2018 did not pass the comparison test, and all other comparisons in 2018 and 2020 passed the Wilcoxon rank sum test.

Properties		CONV	ORG
Geographical properties	Elevation (m)	575	580
	Slope (%)	33.0	31.7
	Heading (°)	143.1	170.3
	Area (m^2)	1234	1051
Management	Planted species	TTES #13 [1]	TTES #12
	Harvest	Machine	Manual
	Weeding	Herbicide	Manual
	Soil surface	Slight amount of moss and dry leaves	Weed
	Canopy structure	Flat	Rough
	Interrow spacing (m) [2]	1.00	1.25
Canopy on 11 Nov 2018	LAI_{Field}	2.73 ± 0.60	4.62 ± 0.79
	LAI_{Crown}	3.88 ± 0.70	5.62 ± 1.28
	FAPAR	0.88 ± 0.05	0.90 ± 0.06
	Canopy height (cm)	49.4 ± 3.34	97.7 ± 9.05
Canopy on 14 May 2020	LAI_{Field}	1.04 ± 0.29	4.11 ± 0.91
	LAI_{Crown}	1.52 ± 0.21	5.32 ± 1.03
	FAPAR	0.48 ± 0.05	0.89 ± 0.04
	Canopy height (cm)	40.5 ± 2.55	80.5 ± 4.50

[1] TTES: Taiwan Tea Experiment Station.

[2] Horizontal distance, not including tilt.

Title

Different management strategies exert distinct influences on microclimate of soil-atmosphere system in tea fields

Authors

Siang-Heng Wang [1, 2] and Jehn-Yih Juang [1, 2, *]

Affiliation

1. International Degree Program in Climate Change and Sustainable Development, National Taiwan University, Taipei, Taiwan
2. Department of Geography, National Taiwan University, Taipei, Taiwan

Corresponding: Jehn-Yih Juang

Abstract

Agricultural management strategies are crucial in regulating the soil-atmosphere interaction. The crop landscape is influenced by farmers through different field practices, and further impacts the variations of soil temperature, soil moisture, and field microclimate. To examine how different management strategies affect the soil properties and the aforementioned interaction, two observation systems were installed in an organic-certified (ORG) tea field and a conventional (CONV) tea field in northern Taiwan. The results show that the variation of canopy temperature was more significant in CONV while the difference in soil diurnal temperature range was minor. However, the daily loss rate of soil water content in ORG was two times faster than that in CONV (0.93% d^{-1} vs. 0.46% d^{-1}). These findings suggest that the appropriate management strategies could assist farmers in adapting to environmental fluctuations and provide quantitative references for assessing soil characteristics under different agricultural applications and climatic conditions.

Keywords: organic; conventional; soil temperature; soil moisture; evapotranspiration (ET); eddy covariance (EC)

Plain Language Summary

In agricultural fields, the farmers frequently utilize different field applications, such as pruning, weeding, or soil loosening, to manage their crops. The application of these different agricultural management strategies usually changes the appearance of the crop canopy, and further influences the soil properties and the water conservation in these crop fields. To quantify how field management influences these properties, two sets of micro-meteorological measurement systems were conducted in an organic-certified and a conventional tea field in northern Taiwan. According to the ensemble average of the measurements, the difference in soil temperature was minor but the difference in canopy temperature was significantly larger in conventional field. However, the daily loss rate of soil water content in the organic-certified field was faster than that in the conventional field. The variation in soil water content was stronger than that in the conventional field. The findings from this study could sufficiently provide quantitative knowledge for field management in the agricultural fields.

Key Points

1. Field management is crucial in soil-atmosphere interaction through the changes in canopy structure and soil properties.
2. The difference in soil DTR is minor, but the loss of soil water content is faster in the organic-certified field than conventional field.
3. High evapotranspiration in the organic-certified tea field corresponds to a high rate of decrease in soil water content.

1. Introduction

The long-term interaction between canopy volume and the dynamics of soil parameters (soil temperature, T_s, and soil moisture) has been investigated through modeling and field surveys (Childs and Flint, 1987; Famuwagun, 2016; Flerchinger and Pierson, 1991; Ritter *et al.*, 2005). Canopy coverage obstructs incident solar radiation, causes changes in surface energy balance and evapotranspiration (ET) (Kustas *et al.*, 2018) and alters T_s through canopy shading (Özkan and Gökbulak, 2017). The partitions of the surface net radiation, sensible heat flux, and latent heat flux are also influenced by variations in canopy coverage (Baldocchi, 1994). Furthermore, canopy coverage influences soil evaporation because of changes in the canopy structure. In addition, evaporation, combined with infiltration and percolation of rainwater and dew in the soil layer, notably contributes to soil moisture dynamics (Wang and Dickinson, 2012).

Vegetation canopy regulates the microclimatic factors of above-ground and underground components through energy and water cycles; thus, canopy coverage plays a supportive role in agriculture (Davis *et al.*, 2019; Gao *et al.*, 2019; Kustas *et al.*, 2018; Lin, 2007; 2010; Özkan and Gökbulak, 2017). Hirsch *et al.* (2018) discovered that agricultural management can influence the spatial pattern of soil evaporation, whose trend is opposite to that of canopy transpiration on a global scale. Canopy coverage directly influences the ratio of transpiration to evaporation

(Lin, 2010; Villalobos *et al.*, 2009) and the dynamics of soil moisture (Lin, 2007). Furthermore, soil moisture is also controlled by ET and ambient temperature through near-surface climate feedback (Berg *et al.*, 2014). High near-surface air temperature might cause an increase in soil moisture due to the less canopy greenness and lower transpiration ability (Zavaleta *et al.*, 2003). A modeling-based study discovered that the effects of the interactions between soil moisture and the atmosphere account for 50% of the effects on T_s, especially in the case of representative concentration pathway 4.5 (RCP4.5) (Diro and Sushama, 2017).

Unlike in forests, the interactions between soil moisture and the atmosphere on agricultural land are readily influenced by the dominant exchange of radiation and moisture through the canopy layer because the vegetation coverage is lower on such land than that in forests. Canopy shading is a key factor influencing the microclimate of agricultural fields (Bhagat *et al.*, 2016). Famuwagun (2016) demonstrated that the canopy shading in a cocoa field reduced T_s 4 months after plantation by approximately 7.7 °C, which indicated that the canopy shading regulated solar heating over different growth periods. With a decrease in the incident radiation, less energy is available for the evaporation of water and for increasing the ambient temperature. In previous studies, a coffee field with higher canopy shading exhibited a 41% and approximately 2 °C lower soil evaporation rate and ambient temperature, respectively, than did a field with lower canopy shading (Lin, 2007; 2010).

Research on soil water content mostly focused on the time series of soil moisture (Almagro *et al.*, 2009; Gao *et al.*, 2019; Liang *et al.*, 2014; Lin, 2010; Zheng *et al.*, 2019) but rarely explored its variations in change rate. These studies have reported on the soil moisture dynamics in various conditions. Because of the limitations of topographical or environmental conditions, crop growth in some fields relies only on rainfall and not on irrigation. Therefore, knowledge on the variations in soil water content after every rainfall event is crucial for farmers and scientists during short-term meteorological fluctuations and in different climate scenarios. However, few studies have investigated the variations in soil moisture in terms of change rate or compared various field management strategies. The present study investigated the patterns of T_s, soil moisture, and ET in two neighboring tea fields with different field management strategies to explore the influence of field management strategies on these microclimate parameters.

2. Study site and methods

2.1. Study site

On-site measurements were conducted in two nearby tea fields (121.7279°E, 24.9645°N, elevation ~600 m above sea level) on a hilly terrain in Pinglin Township, New Taipei City, northern Taiwan, which is a region in which tea cultivation is the leading occupation (Wang and Juang, 2022). The tea fields in the Pinglin region have desirable canopy heights, crown sizes, leaf area density, and corridor width that satisfy the expectations of the farmers. The farmers in this region adopt management strategies based on their long-term local experience, and modification of the canopy structure is the primary approach for applying these strategies. For example, tea farmers frequently shape the tree crown by pruning the branches and leaves to modify the sunshine, ventilation, and water statuses of their field. Therefore, the analysis of the microclimate of the study area by comparing the energy components and soil parameters in nearby fields with similar meteorological and geographical conditions can enhance the fundamental understanding on how field management affects the microclimate.

The two neighboring tea fields (separated by approximately 100 m) investigated in this study, in which different management strategies are used (Table 1), exhibit similar environmental and geographical parameters, including topographic slope, orientation, fetch area, elevation, and sky openness (Wang and Juang, 2022). One of the fields is an organic-certified field (ORG) in which labor-intensive applications, such as manual weeding and harvesting, are relatively common. By contrast, the other field is a conventional field (CONV) in which farmers typically use herbicide to eliminate weeding and adopt machines for harvesting.

Because the strategies adopted by the farmers are different for the two fields, their canopy structures are controlled and shaped through field operations. The tea tree crown in ORG was taller and more extensive than that in CONV. Furthermore, the ground surface in ORG was notably covered by weed, whereas the ground surface of CONV was not covered by weed because of the frequent usage of herbicide but was covered with dry leave debris. Research (Wang and Juang, 2022) conducted at this study site indicated that ORG, which had a wider and taller canopy than did CONV, exhibited a higher latent heat flux (25%) and lower sensible heat flux (10%) than did CONV. Furthermore, after the tea buds were harvested, the sensible heat flux increased by 51.5% in CONV but only by 9.6% in ORG.

Although Pinglin is a wet area (the long-term annual rainfall is approximately 4,000 mm), the seasonality in rainfall is notable (the rainfall is approximately 200 mm during spring but exceeds 1,000 mm during autumn). The rainfall patterns over different seasons were compared according to the accumulative rainfall acquired from five automatic weather stations and one meteorological station of the Central Weather Bureau in Taiwan near the study fields.

2.2. Physical properties of the soil in the two fields

Because the two tea fields managed using different strategies were adjacent to each other, the physical properties of the soil layers in these fields were affected by the different farmers' applications in the fields on a long-term basis. For example, the biological activities and root systems in ORG were more likely to cause the soil to loosen than were those of CONV. Measuring soil bulk density is a common method for characterizing soil structural properties (Dexter, 2004; Rabot *et al.*, 2018).

Soil bulk density was measured from soil samples excavated from the northern, middle, and southern sides of the corridor near the soil moisture sensor. The volume and depth of the sampling core were 98 cm^3 and 5 cm, respectively. Before sampling was performed, the bulk debris cover on the soil surface was carefully removed, but the humus in the soil was kept intact. The core was vertically inserted into the soil, after which the soil samples were excavated. The sample tube was then covered using a plastic lid to avoid evaporation. Each soil sample was dried at 105°C for 24 h. The dried soil samples were then weighed, and the bulk density was calculated as the dried soil weight divided by the core volume (Klute, 1986).

2.3. Soil temperature, canopy temperature, and soil moisture measurement

In the study region, tea plants are typically planted in rows in parallel corridors, and the landscape has an inhomogeneous appearance. This inhomogeneity was expected to influence the representativeness of the measurements and should be considered when assessing the soil layer (Michot *et al.*, 2003). To consider the spatial representativeness of the tea fields, pairs of soil temperature and water content sensors (Drill and Drop, Sentek Inc., Stepney, SA, Australia) were installed on the northern and southern corridors near an eddy-covariance (EC) flux system in each field. The detectors were placed 5 cm below the ground surface to perform measurements from June 2019 to October 2020. The canopy temperature (T_c) were measured at the tree crown by a T-type thermocouple with radiation shield. The data was collected using a data logger (CR1000X, Campbell Scientific, Inc., Logan, UT, USA) at a sampling frequency of 1 min^{-1}.

The measurement data collected from the winter of 2019 to the autumn of 2020 were divided among four seasons because the ground surface temperature was sensitive to solar radiation. To quantify how field applications affect the patterns of field temperature, the half-hourly time series of temperature difference between T_c and T_s (T_c-T_s) were obtained for further analysis.

2.4. ET measurement

ET was estimated using an EC flux system composed of a 10-Hz sonic anemometer (CSAT-3, Campbell Scientific, Inc., Logan, UT, USA), and an open-path CO_2/H_2O gas analyzer (LI-7500, Li-Cor Inc., Lincoln, NE, USA) in each field (Wang and Juang, 2022). The EC equipment was set at heights of 1.5 m (canopy height of 1.0 m) and 1.0 m (canopy height of 0.5 m) in ORG and CONV, respectively. ET data were collected using the CR1000X data logger, and the 30-min mean ET values were calculated using the EddyPro v6.2.2 software (Li-Cor Inc., Lincoln, NE, USA). In addition, the fetch area of the flux measurement was estimated using a R package (FREddyPro v1.0). Although both fields are small (Table 1), over 90% of the flux originated from the fields because the measurement heights were low.

3. Results and discussion

3.1. Soil bulk density

According to the analysis of physical properties, the soil bulk density was 1.19 ± 0.02 g cm^{-3} in CONV and 1.10 ± 0.10 g cm^{-3} in ORG. The lower bulk density in ORG was likely on account of the higher abundance of organisms and weed roots in the soil layer in ORG because no pesticide or herbicide was used in this field. In ORG, the organisms in the soil caused the soil structure to loosen, increased the porosity for air and water, and decreased the soil aggregate stability for root development. The higher variation in soil bulk density in ORG (0.10 g cm^{-3} in

ORG and 0.02 g cm^{-3} in CONV) was consistent with these results (Rabot *et al.*, 2018). The lower aggregate stability in ORG than in CONV promoted infiltration more effectively in ORG, thereby resulting in less surface runoff in ORG (Rabot *et al.*, 2018).

3.2. Soil temperature, canopy temperature and temperature difference

T_s in the fields was influenced by canopy coverage and seasonal variation (dependent on incident solar radiation). To quantify the diurnal temperature range (DTR) over different seasons, the ensemble average of the 30-min data in CONV and ORG was converted into the DTR (the difference between each 30-min data point and the first data point) over different seasons (**B1** to **B4** in Figure 1, from the winter of 2019 to the autumn of 2020). In ORG, the DTR over the seasons was highly similar; however, the DTR in CONV was higher during autumn and winter than during other seasons. The results indicated that the DTR in CONV was higher than that in ORG during autumn (4.69 °C in CONV vs. 3.95 °C in ORG) (Figure 1 **B4**), and the DTR in CONV was lower than that in ORG during winter (2.85 °C in CONV vs. 3.07 °C in ORG) (Figure 1 **B1**). Although the DTR in autumn and winter were noticeable, the ensemble average over all seasons indicated that the DTR in CONV was similar to that in ORG (2.50 °C in CONV vs. 2.46 °C in ORG). The T_s difference in ensemble average was not significant (the maximum difference is 0.46 °C at 11:00, Figure 2 **A**).

Compared to the difference of DTR in T_s, the difference of dynamics in T_c was more notable. T_c in CONV was 0.86 °C (46.5%) higher than ORG around noon (9:00-15:00), and 0.36°C (22.3%) lower than ORG during nighttime (21:00-3:00).

As indicated by the canopy structure, the canopy coverage in ORG was higher than that in CONV (leaf area index, was 4.11 in ORG and 1.04 in CONV on May 14, 2020, as reported by Wang and Juang (2022)). An obvious heating effect in CONV occurred around the canopy (0.86 °C) due to its shorter height.

A previous study has indicated that a higher canopy shading in a coffee field can result in a lower field temperature and more beneficial to microclimate (Lin, 2007). The shading effect of a higher canopy coverage attenuates the radiation incident on the ground surface and might increase the shade tolerance of some organisms in the understory layer (Valladares *et al.*, 2016). De Frenne *et al.* (2013) reported that in addition to moderating the microclimate, a dense forest canopy might result in thermophilization lag under the forest canopy. Canopy shading has notable influence on ecophysiological characteristics, and more active abiotic and biotic ecosystem dynamics in higher shading area are observed within the canopy volume (Valladares *et al.*, 2016). Therefore, the canopy coverage in this study showed an obvious influence on the dynamics of T_c.

3.3. Soil moisture

From the data shown in Figure 1, there was no correlation pattern between the seasonal accumulative rainfall (**A1** to **A4** in Figure 1) and the consecutive daily soil water content between every rainfall events (**D1** to **D4** in Figure 1). Because Pinglin is a wet region that receives 4,000 mm of rainfall annually and a considerable amount of dew water in the morning, soil water content did not exhibit seasonal variation. The results indicated that the median daily mean soil water content after rainfall was 28.5% in CONV and 30.6% in ORG. Furthermore, after 7 days, the median changed to 24.9% in CONV and 20.7% in ORG (Figure 3 **A**). Overall, the average daily loss rate was 0.46% d^{-1} in CONV and 0.93% d^{-1} in ORG.

A study indicated that the soil water content in organic field was higher than that in conventional field because of the higher capacity of organic field to retain soil water (Lotter *et al.*, 2003). In the present study, similar results were obtained for soil water content after the rainfall event (CONV vs. ORG: 28.5% vs. 30.6%). However, the rate of soil water loss in ORG was higher than that in CONV 7 days after the rainfall event, thereby which resulted in the soil water content being lower in ORG (CONV vs. ORG: 24.9% vs. 20.7%). Lin (2010) found that lower shading in a coffee field resulted in higher soil water loss in the wet and dry seasons. However, in this study, the soil water content between rainfall events was initially 1.2% higher in ORG but then became lower with time (4.2% lower compared with CONV). This pattern indicates that the loss rate of water content was higher in ORG than in CONV.

During the first 4–5 days after a rainfall event, the daily soil water content decreased more notably in ORG than in CONV (**D1** to **D4** in Figure 1). The daily loss rate was higher on the first 4 days than on the later days (Figure 3 **B**). After the rainfall events, the median of the daily loss rate of soil water content was 0.58% d^{-1} in CONV and 0.77% d^{-1} in ORG. On the 3rd to 4th day, the daily loss rate in CONV and ORG were 0.42% d^{-1} and 1.29% d^{-1}, respectively. On the 6th to 7th day, the rate in CONV was 0.21% d^{-1}, and the rate in ORG was 0.71% d^{-1}. The daily loss rate from the 1st and 2nd days to the 4th and 5th days in the two fields were significantly different ($p < 0.05$) (Figure 3 **B**). Overall, the soil moisture dynamics in ORG were stronger than those in CONV. In ORG, the daily loss rate of soil water content increased from the beginning to the following rainfall event, but a retard situation occurred on the 4th day. The relatively fast loss of soil water content in ORG was consistent with the low soil bulk density in ORG, which resulted in a higher infiltration rate in ORG than in CONV. Therefore, the soil moisture dynamics in ORG were stronger than those in CONV.

The distribution of weed roots in ORG increased the soil porosity in ORG and caused an increase in the water holding capacity of the soil during rainfall events.

However, the increased porosity of the soil layer facilitated the evaporation of soil water after rainfall (Or *et al.*, 2013). In addition, transpiration in the weeds in ORG resulted in the loss of soil water. Moreover, the ground surface of CONV was covered with leaf debris (formed during tea plant trimming) that caused a decrease in evaporation by blocking direct solar heating. Therefore, the soil water content in ORG increased after rainfall but later decreased at a high rate, and the rainwater holding ability of the soil in CONV was higher than that of the soil in ORG.

3.4. Evapotranspiration

The difference in the daily loss rate of soil water content in terms of the ET pattern between the two fields was considerably large. The ET rate was 6.27 mm d^{-1} in CONV and 8.38 mm d^{-1} in ORG, which indicated that the ET in ORG was 33.8% higher than that in CONV. The most significant difference occurred around noon (from 10:00 to 14:00 LT). The ensemble average and maximum values of the ET in ORG over 30 min were 0.480 and 0.535 mm, respectively, and the corresponding values in CONV were 0.351 and 0.412 mm, respectively. These results were obtained around mid-day and indicated that the ET in ORG was approximately 36.8% higher than that in CONV (Figure 2). The ET patterns in the two fields were significantly different ($p < 0.001$), especially during the day (7:30–17:00). Thus, according to the ET pattern and soil water content, the loss of soil water from the ground surface in ORG was higher than that in CONV, which contributed to the ET in ORG.

The higher ET in ORG than in CONV was attributable to the taller and wider canopy structure of the tea plants and the weeds covering the ground surface in ORG. Compared to that in ORG, the tea tree canopy in CONV was shorter, thereby limiting the loss of water. The present study did not distinguish between evaporation and transpiration in the tea fields. However, according to field observations in previous studies, the long-term evaporation of soil water in CONV is limited by the leaf debris covering the ground surface (Facelli and Pickett, 1991). Transpiration had a notable influence on the ET in ORG because of the higher canopy volume in ORG than in CONV, as indicated by the leaf area index (LAI). By contrast, soil evaporation had a considerably low contribution to the ET in the Pinglin region because the annual rainfall in the region was approximately 4000 mm and the landscape was primarily covered with vegetation that contributed to water conservation.

W. Todd *et al.* (1991) suggested that wider canopy coverage on the ground surface reduced the evaporation in a corn field. Another study reported that a larger shading area in a coffee field decreased the rate of loss of the soil water content (Lin, 2010). The present study indicated that a tea field with a larger canopy coverage exhibits higher ET and superior soil moisture dynamics between rainfall events. Therefore, a larger canopy coverage contributes to enhancing ET, and the canopy volume is higher because of higher LAI (Wang *et al.*, 2014).

4. Conclusions

In the tea cultivation industry, the various management strategies adopted by tea farmers according to their expectations typically involve altering canopy structures and the microclimate of the tea field. In this study, we performed a series of measurements and analyses to examine the outcomes of different management strategies in terms of T_c, T_s, soil moisture, and ET in two neighboring tea fields in northern Taiwan. The results indicated that field applications (organic-certified and conventional methods) corresponded to differences in surface heating and soil moisture through the modification of canopy coverage.

The shorter and narrower canopy coverage in CONV than in ORG resulted in a lower rate of decrease in soil moisture after each rainfall event in CONV (–0.46% d^{-1}) than in ORG (–0.93% d^{-1}). This result was consistent with the ET pattern and indicated that the rate of ET in ORG was 2.11 mm d^{-1} (33.8%) higher than that in CONV (6.27 mm d^{-1} in CONV and 8.38 mm d^{-1} in ORG) because the canopy and weed in ORG tended to release more soil water through the root system. Furthermore, the higher ET leads to lower canopy temperature in ORG than in CONV (0.86 °C or 46.5%). In addition, the rate of decrease in soil moisture in the two fields changed drastically 3-4 days after rainfall. The loss rate was faster in the first 3-4 days than the later days, and this pattern was more significant in ORG. The lower soil bulk density in ORG can be attributed to the higher rate of decrease in soil moisture. The inverse relationship between bulk density and variations in soil water content in this study is consistent with the concept of least limiting water range (LLWR) introduced by da Silva *et al.* (1994).

The strategies used for soil water management in tea fields can serve as references for water resource management in agricultural land at the regional scale. These strategies can also help farmers determine the extent of trimming and weeding required to offset the influence of rain and drought events (Bhagat *et al.*, 2016). Lotter *et al.* (2003) reported that the water holding capacity of soil in organic crop fields is higher than in other fields. The high water holding capacity of soil is crucial for controlling the interactions between soil moisture and the atmosphere (Diro and Sushama, 2017). It dominates the energy budget (Flerchinger *et al.*, 2003) and can effectively retard floods caused by frequent extreme climate fluctuations. Furthermore, T_s and soil moisture are essential parameters that influence the crop yield (Liu *et al.*, 2013), hydrological cycle (Robinson *et al.*, 2008), biological process, and various physical responses (Legates *et al.*, 2011).

Although the influence of diurnal soil temperature difference on surface temperature is unclear, the results suggest the high correlation between coverage and surface temperature. Canopy coverage or shading in the field can moderate the surface temperature in the long term and mitigate the tradeoffs. Godinho *et al.* (2016) reported that the higher canopy coverage could lower surface temperature. In addition, the existence of cover crops could reduce soil erosion under extreme rainfall (Kaye and Quemada, 2017). Besides the geophysical effects, Schmitzberger *et al.* (2005) reported that ecofriendly agriculture has relatively low economical turnover but provides high biodiversity value. Although ecofriendly agriculture produces relatively low yields (Maeder *et al.*, 2002), the demand for fertilizers and pesticides is considerably lower than that in conventional agriculture (Schmitzberger *et al.*, 2005; Zhang *et al.*, 2018). Furthermore, organic farms have high biodiversity (Maeder *et al.*, 2002) and ecofriendly planting might increase the resilience of crop fields against rigorous climate. The results and data of this field study can serve as background information for numerical models for assessing soil characteristics as the outcomes of different management strategies and different climatic conditions.

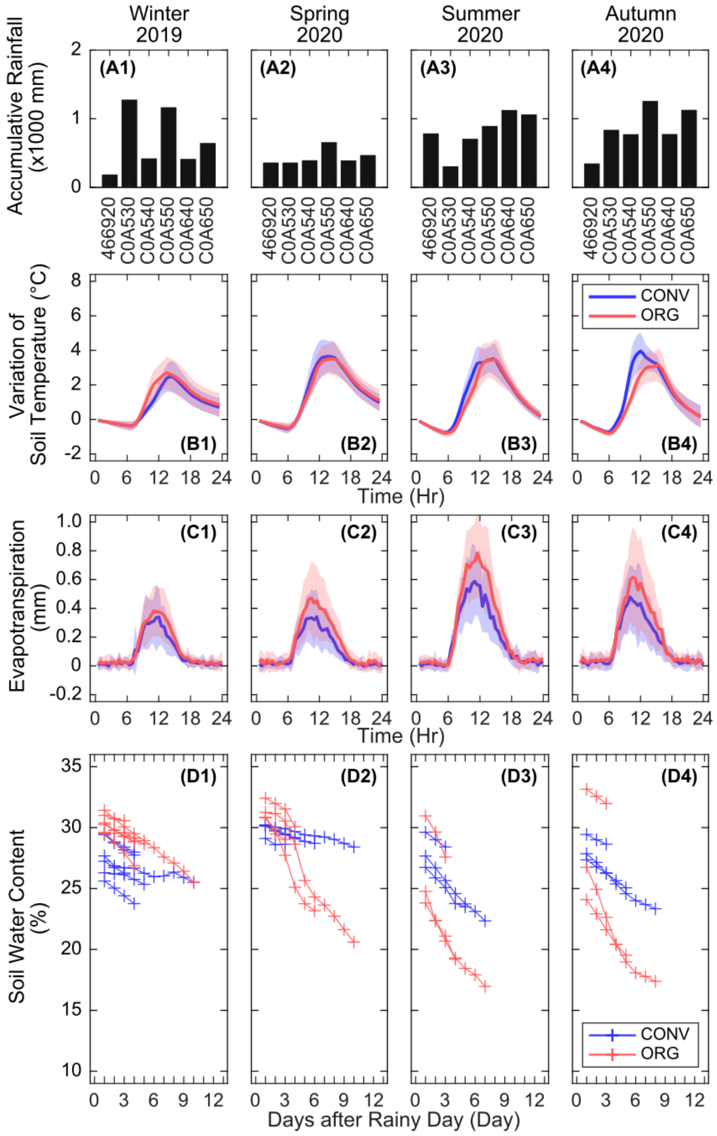


Figure 1 Seasonal cumulative rainfall **(A1 to A4)**, soil temperature **(B1 to B4)**, ET **(C1 to C4)**, and soil water content **(D1 to D4)** from the summer of 2019 to the autumn of 2020. Rainfall data were captured at six weather stations (466920: Taipei, C0A530: Pinglin, C0A540: Sihdu, C0A550: Taiping, C0A640: Shihding, C0A650: Huoshaoliao) of the Central Weather Bureau.

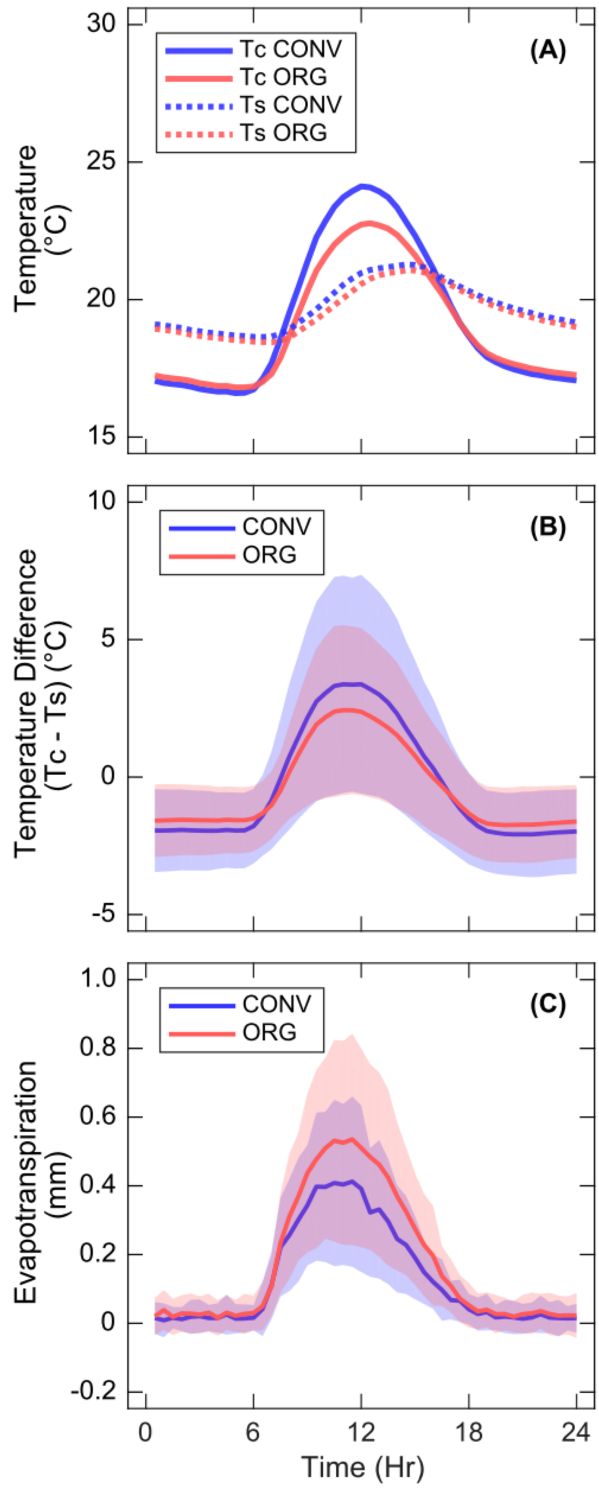


Figure 2 **(A)** Ensemble average of canopy temperature (T_c) and soil temperature (T_s), **(B)** difference between T_c and T_s, and **(C)** ensemble average values of ET during the measurement period. The solid lines and dotted lines are the ensemble averages, and the shadow area represents one standard deviation.

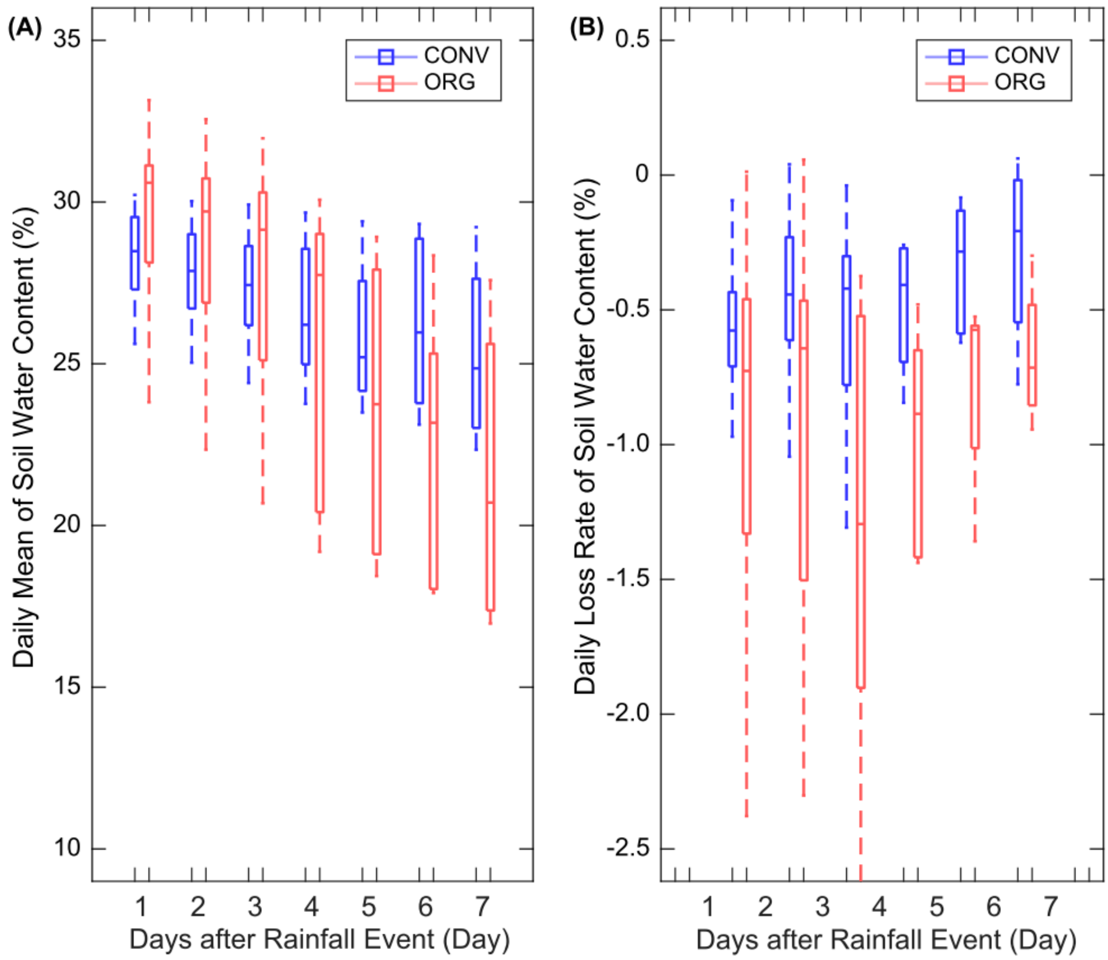


Figure 3 Daily mean (A) and daily loss rate (B) of soil water content between rainfall events. The legends in the box plot from the top to the end are the maximum (upper boundary of the dashed line), third quantile (upper boundary of the box), median (middle of the box), first quantile (lower boundary of the box), and minimum (lower boundary of the dashed line) values. The conditions of capturing rainfall data for daily loss rate were as follows: daily rainfall of less than 0.8 mm; the daily rainfall on the previous day did not exceed 1.2 mm; and the data for only 2 successive days were excluded.

Table 1 Geographical properties, management strategies, and canopy properties of the two investigated tea fields. The statistical result of FAPAR in 2018 did not pass the comparison test, and all other comparisons in 2018 and 2020 passed the Wilcoxon rank sum test.

Properties		**CONV**	**ORG**
Geographical Properties	Elevation (m)	575	580
	Slope (%)	33.0	31.7
	Heading (°)	143.1	170.3
	Area (m^2)	1234	1051
Management	Planted species	TTES #13[1]	TTES #12
	Harvest	Machine	Manual
	Weeding	Herbicide	Manual
	Soil surface	Slight amount of moss and dry leaves	Weed
	Canopy structure	Flat	Rough
	Interrow spacing (m)[2]	1.00	1.25
Canopy on 11 Nov 2018	LAI_{Field}	2.73 ± 0.60	4.62 ± 0.79
	LAI_{Crown}	3.88 ± 0.70	5.62 ± 1.28
	FAPAR	0.88 ± 0.05	0.90 ± 0.06
	Canopy height (cm)	49.4 ± 3.34	97.7 ± 9.05
Canopy on 14 May 2020	LAI_{Field}	1.04 ± 0.29	4.11 ± 0.91
	LAI_{Crown}	1.52 ± 0.21	5.32 ± 1.03
	FAPAR	0.48 ± 0.05	0.89 ± 0.04
	Canopy height (cm)	40.5 ± 2.55	80.5 ± 4.50

[1] TTES: Taiwan Tea Experiment Station.

[2] Horizontal distance, not including tilt.

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Open Research

Data Availability Statement

The measurement data is available at https://doi.org/10.1088/1748-9326/ac4361 (Wang and Juang, 2022), and the climate data is available at Central Weather Bureau, Taiwan (https://www.cwb.gov.tw/V8/E/D/Data_Application.html)

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